EFFECTS OF INITIAL CONDITIONS ON EMERGENCE OF DISSOLUTION PATTERNS IN ROUGH FRACTURES

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Outline

- Applications

- Dissolution Physics

- Problem Statement

- Approach

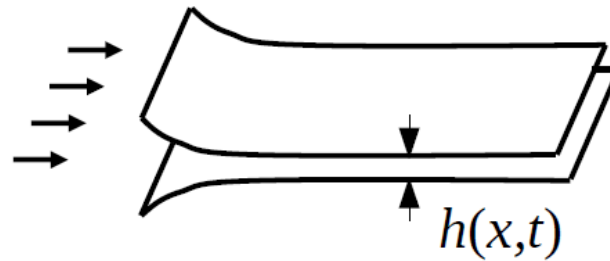- Simulation method

- Observations

Applications

- The evolution of permeability in fracture networks affects these issues:
  - CO_2 Sequestration
  - Dam safety
  - Risk assessment of contaminant migration in ground water
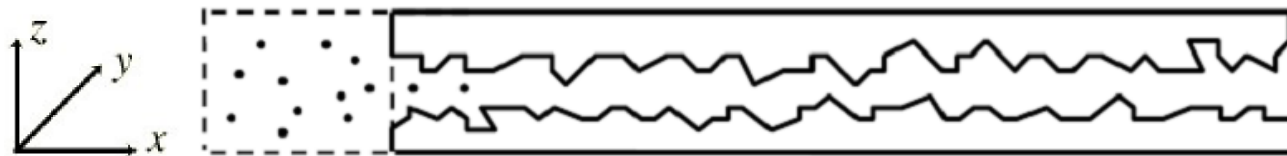 - Modeling reservoirs

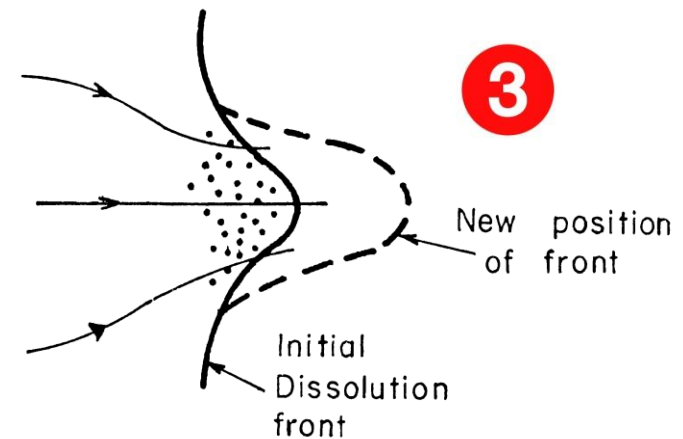# Dissolution Physics: Reaction Infiltration Instability (RII)
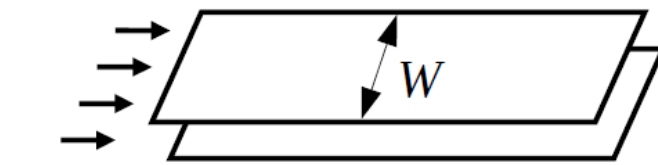
Growth of a finger
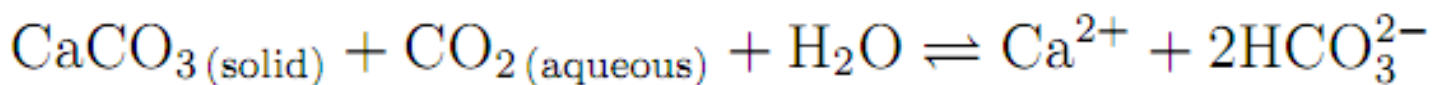Reference: Ortoleva et. al, 1987

$$CaCO_{3\,(solid)} + CO_{2\,(aqueous)} + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^{2-}$$

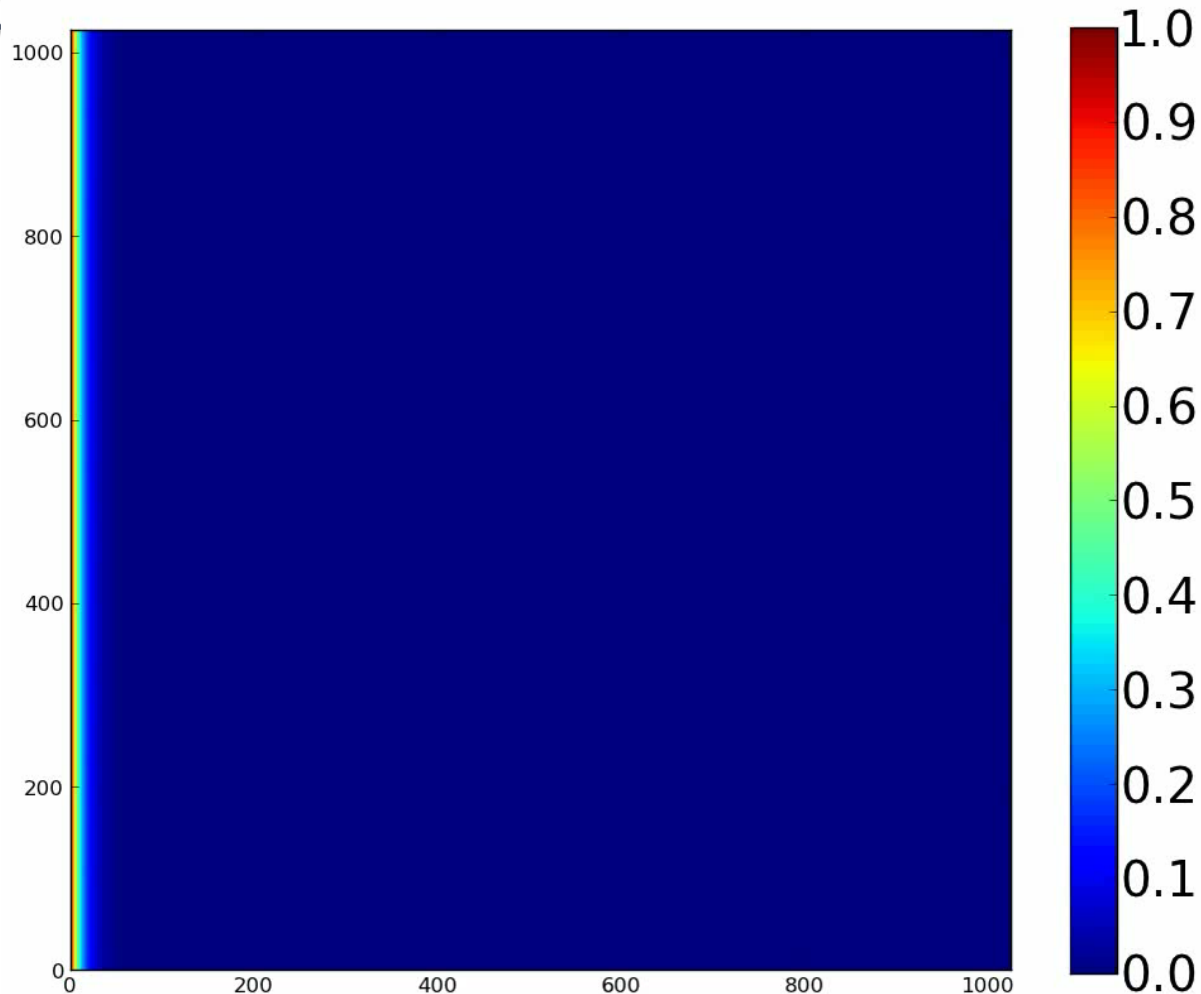# Example:

Ca^{2+} concentration field in the bulk

Size: 10mx10mx1mm

time scale ~ 5 years

Problem Statement

- Earth's geology is constantly changing due to dissolution and precipitation of minerals (diagenesis)

- Are the geomorphologies observed today largely reflected by state of the early earth?

- Or do they "emerge" from the dynamics of dissolution?

# Crossing large time scales by numerical simulation

- My project: Examine the emergence of dissolution patterns from different initial conditions in a fractured rock.

- Simple model system:

  - Fluid flow (Darcy's law) $\nabla.\boldsymbol{q} = 0,\ \boldsymbol{q} = -\dfrac{h^3}{12}\dfrac{\nabla p}{\mu}$

  - Reactant transport $\boldsymbol{q}\nabla.c - D(\nabla h.\nabla c) = 2R(c)$

  - Mineral dissolution at

    the fracture surfaces $c_{sol}\dfrac{\partial h}{\partial t} = 2R(c)$

Simulation method

- Finite difference method

- Structured mesh

- Periodic boundary conditions in Y – direction

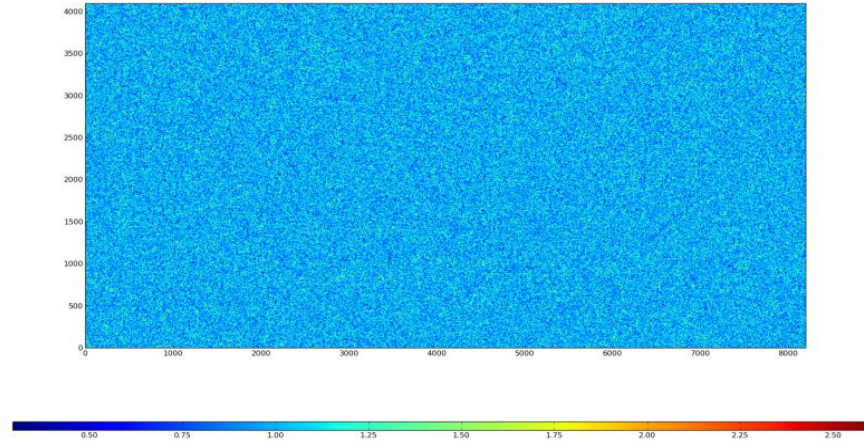- Dirichlet boundary conditions in X – direction

- Linear kinetics

Approach: Initial Conditions

- Randomly generated aperture where adjacent heights are correlated
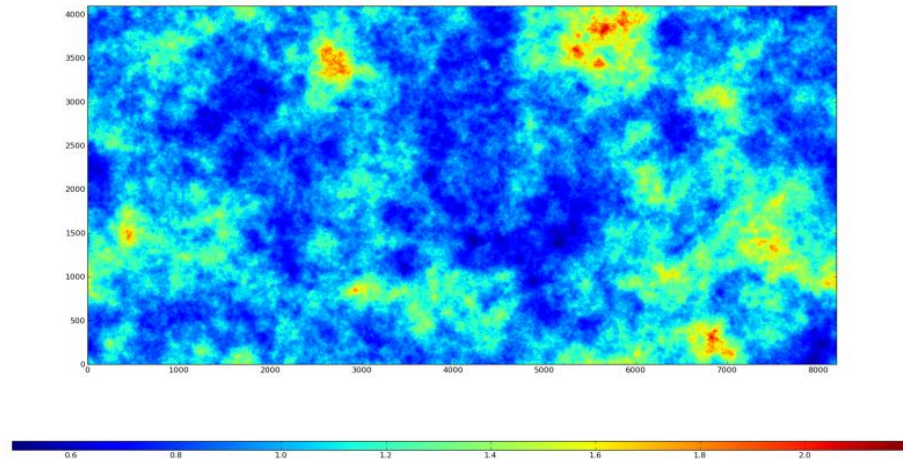- Aperture field $h(x,y)$ characterized by:
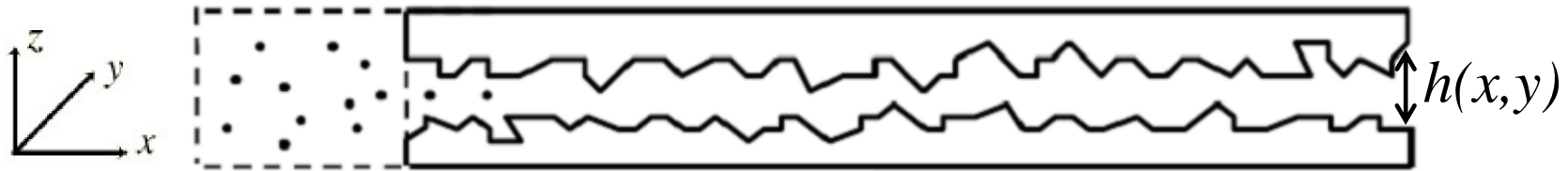
  - mean height (h_0)
  - variance in height – roughness (σ)
  - correlation length (γ)

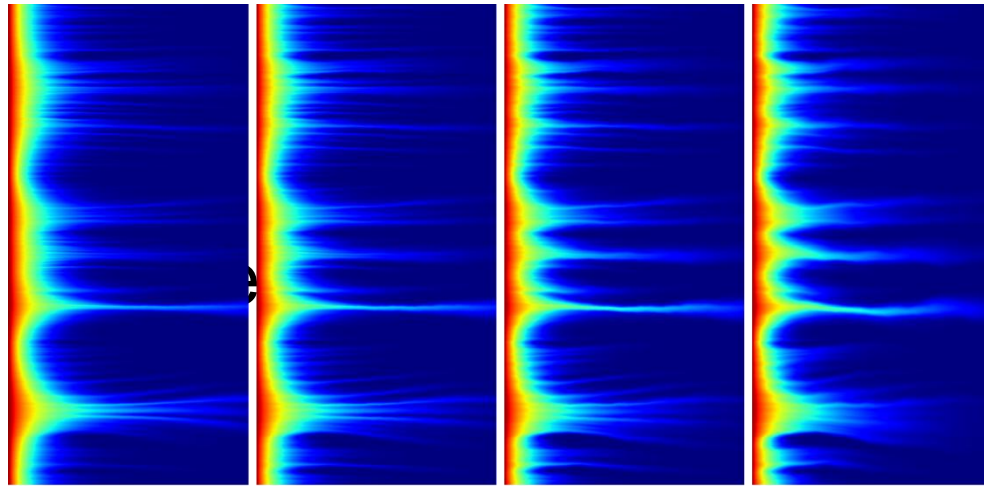# Initial height maps $\sigma = 0.2\ h_0$

$\gamma = 4\ h_0$

$\gamma = 400\ h_0$

Observations

Varying correlation lengths (γ)
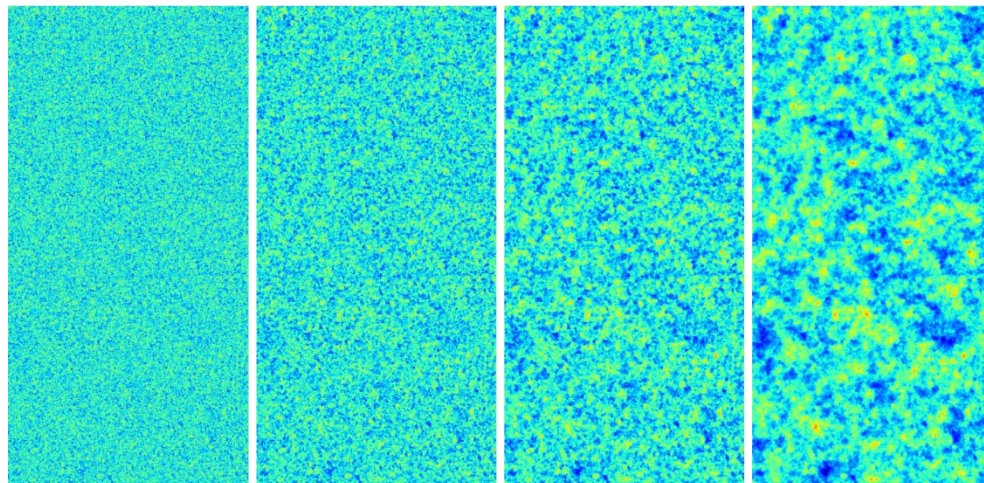
- Correlation lengths do not affect dissolution patterns

Concentration
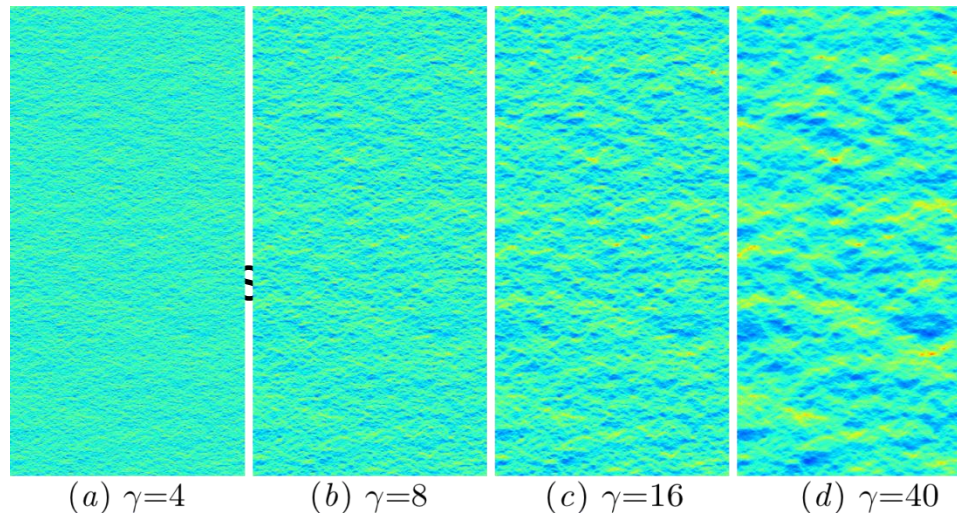
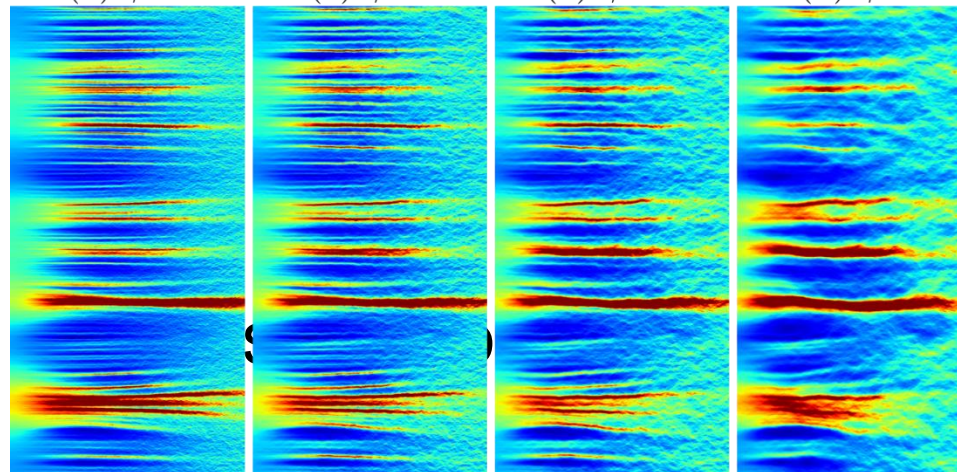(a) $\gamma=4$ (b) $\gamma=8$ (c) $\gamma=16$ (d) $\gamma=40$

Initial height maps

Varying correlation lengths (γ)

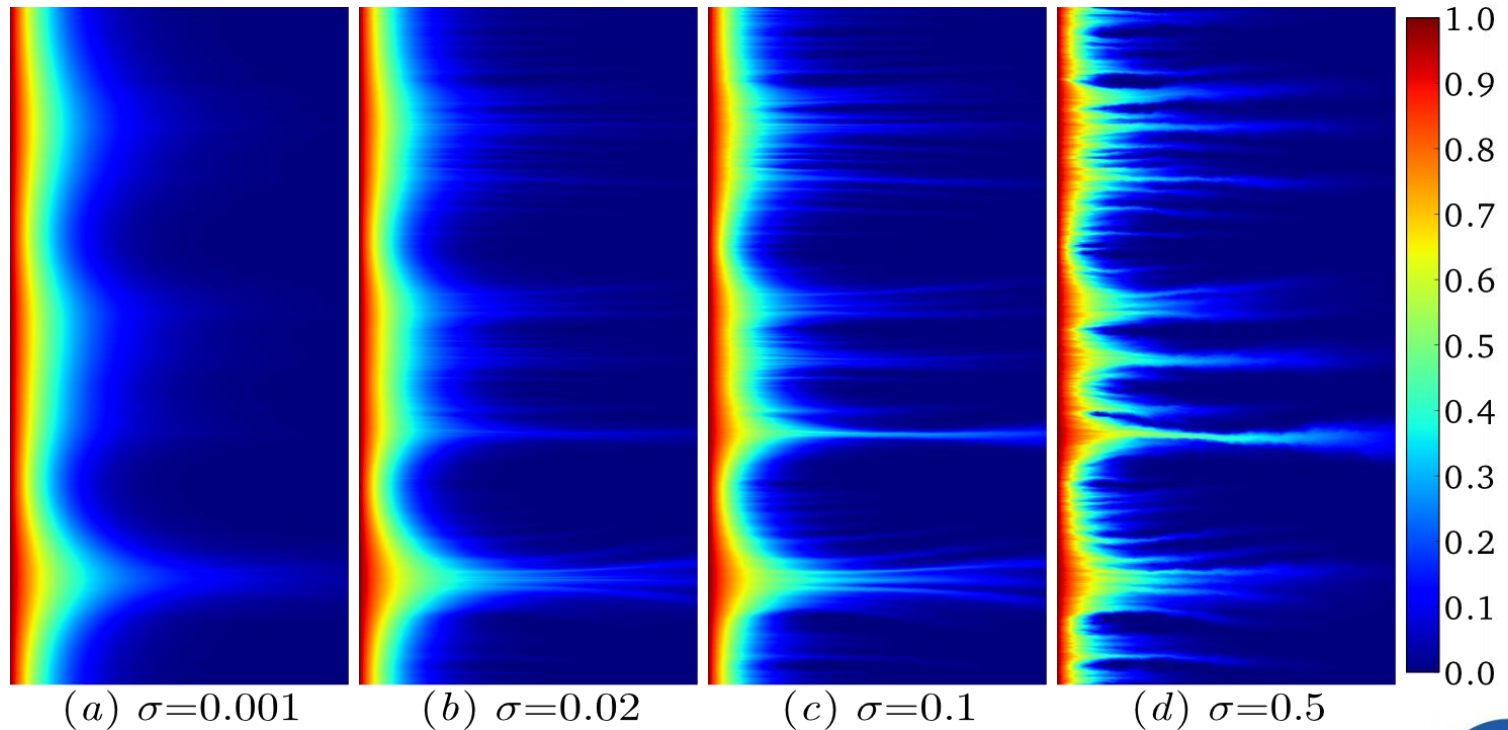- RMS velocity fields not affected by correlation lengths

q_{RMS} before

(a) $\gamma=4$ (b) $\gamma=8$ (c) $\gamma=16$ (d) $\gamma=40$

q_{RMS} after

Varying roughness (σ)

- Roughness doesn't affect dissolution patterns

Concentration field

(a) $\sigma=0.001$ (b) $\sigma=0.02$ (c) $\sigma=0.1$ (d) $\sigma=0.5$

Average flow-rate in the fractures

Roughness (σ)

q/q_0

$\gamma = 4$

Breakthrough

Correlation length (γ)

$\sigma = 0.1$

Breakthrough

t/t_d

Height map

$\sigma = 0.05$
$\gamma = 40$
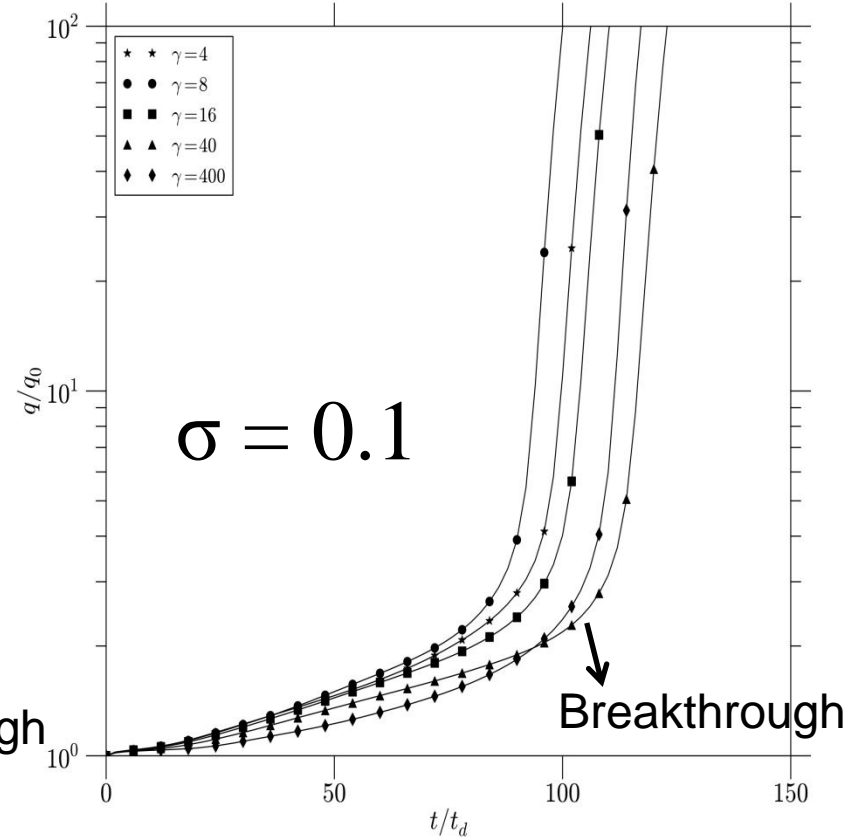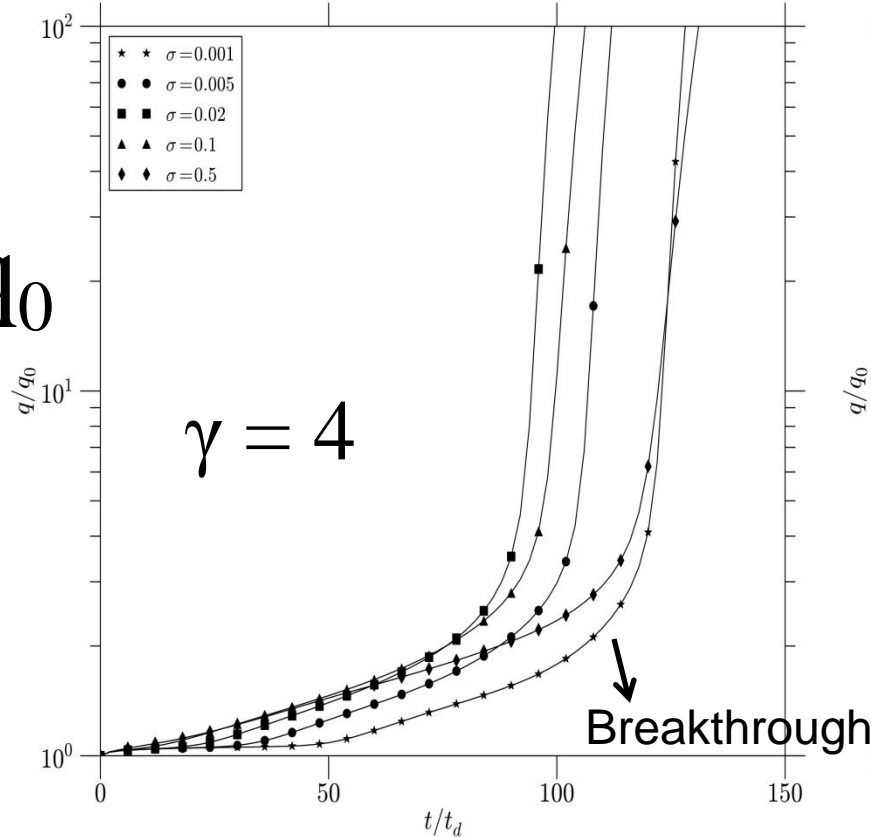
Length of 3 channels ≥ L
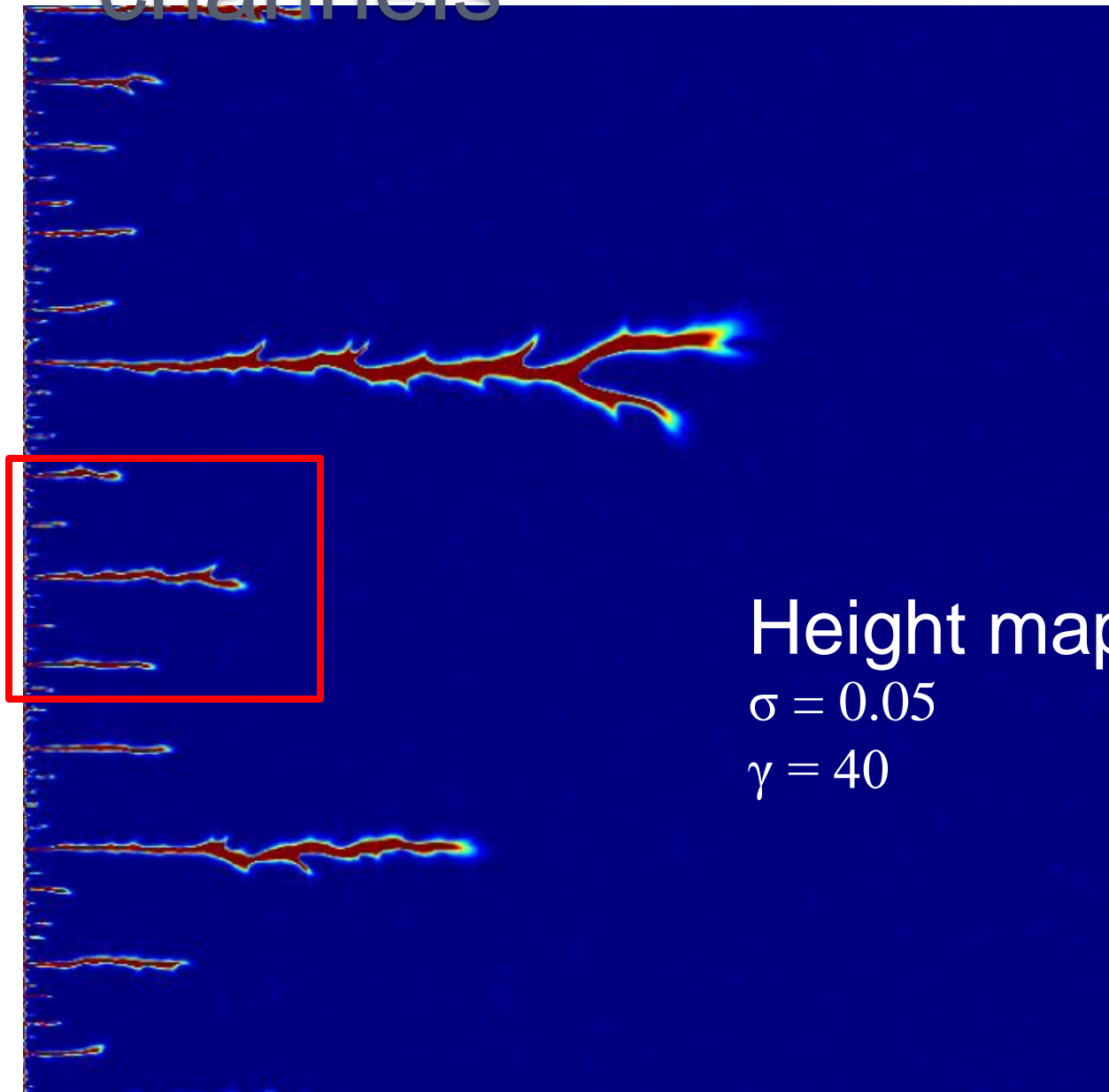
Number of channels as a function of length

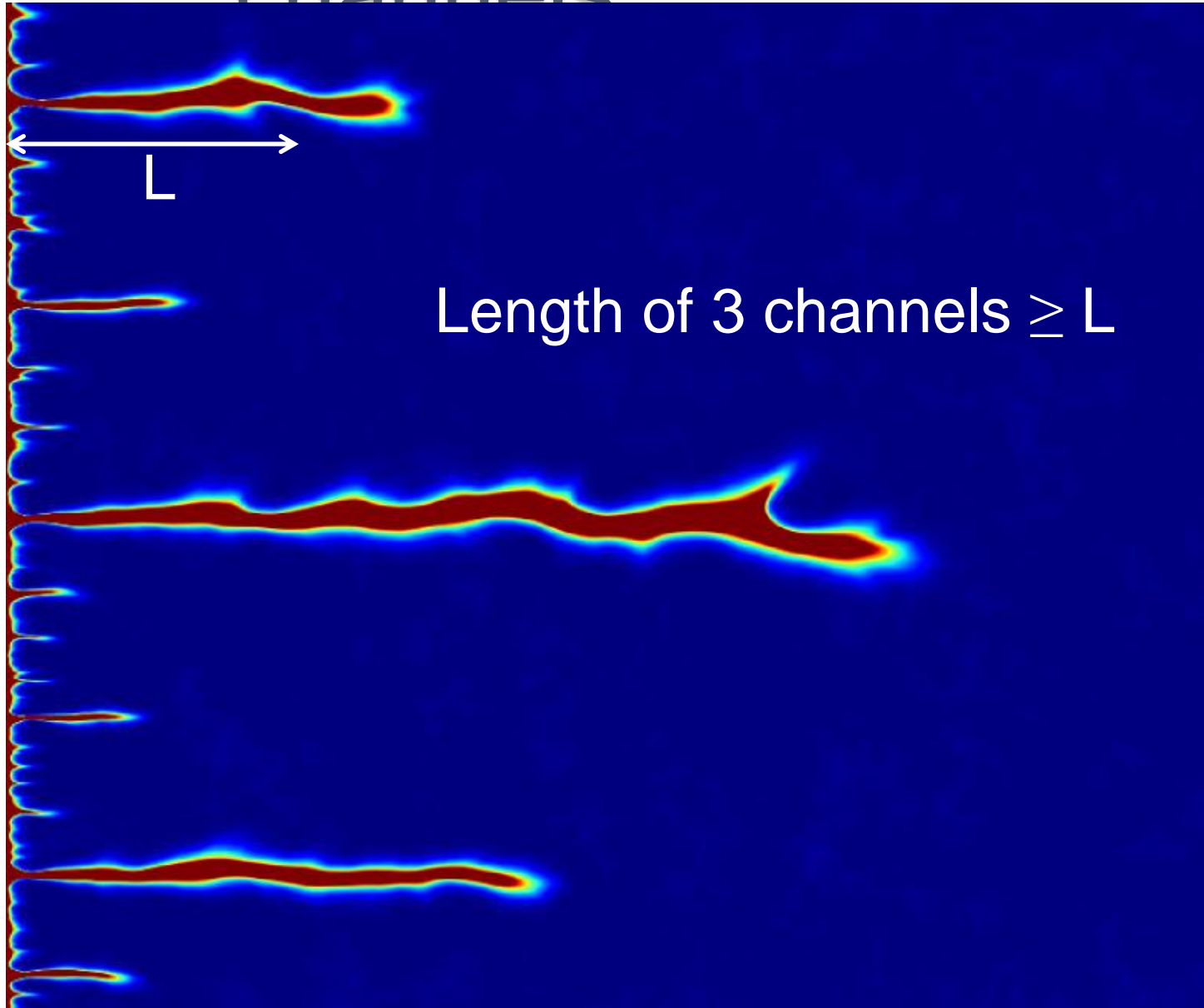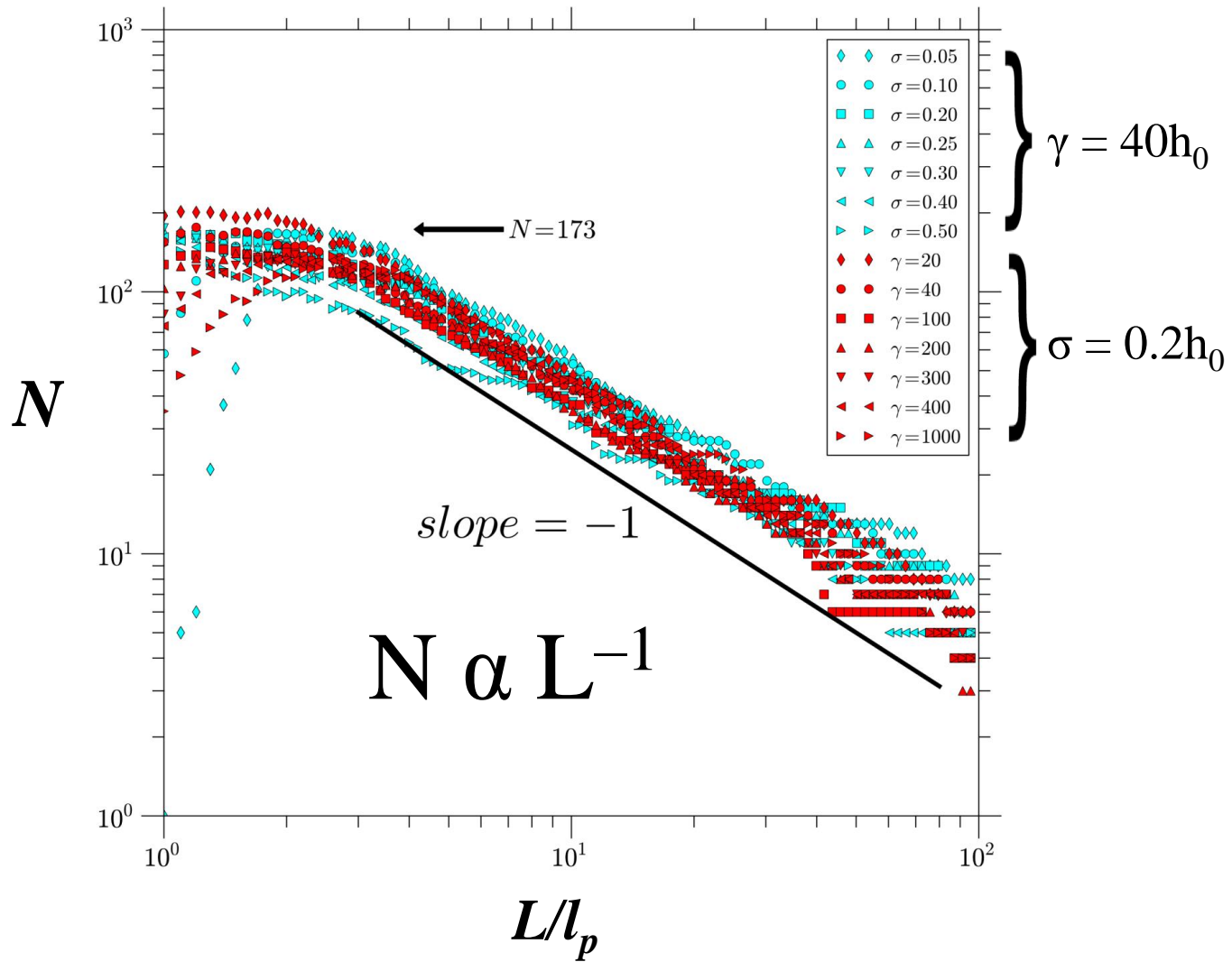- Consistently observed $150 < N < 200$ channels at $L = l_p$ reducing to $N = 2$ or 3 channels at $L = 100 l_p$

$$N \propto L^{-1}$$

Introducing a local perturbation

- Local perturbation added over existing height map
- Seed dimensions 1% of fracture dimensions
- Competition between seed and natural instability
- Does the natural instability still overcome the seed?
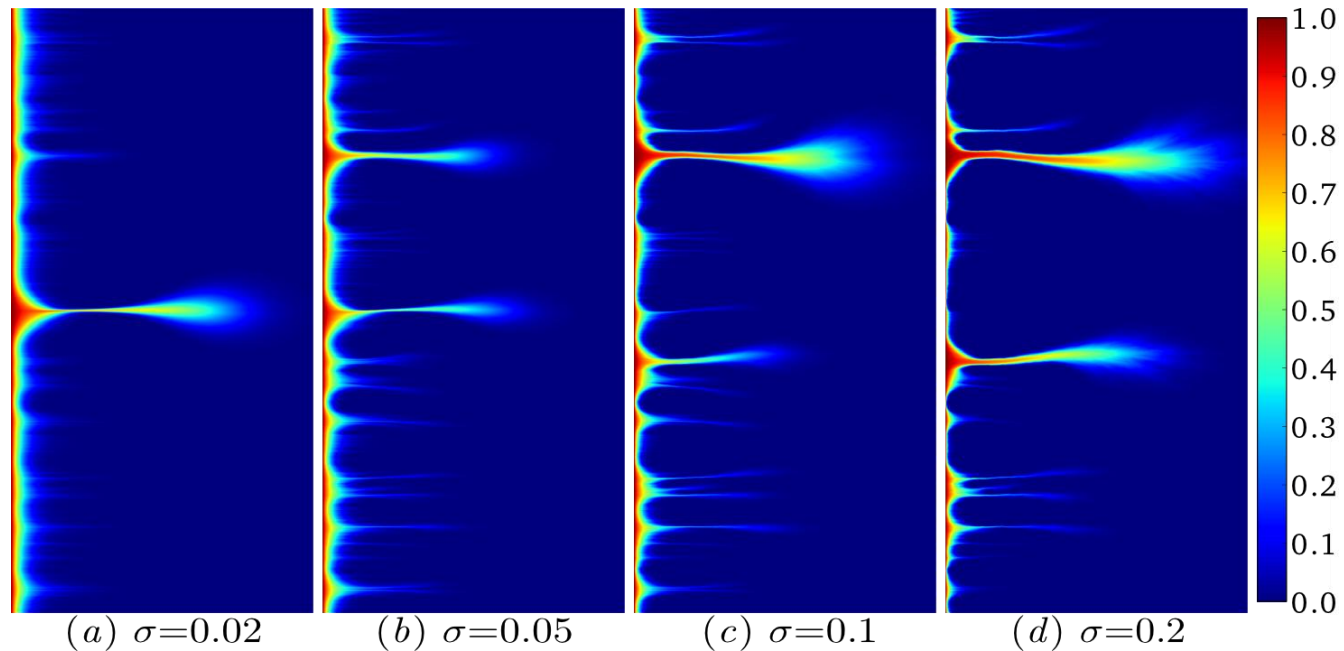
Seeded channel added to Height map
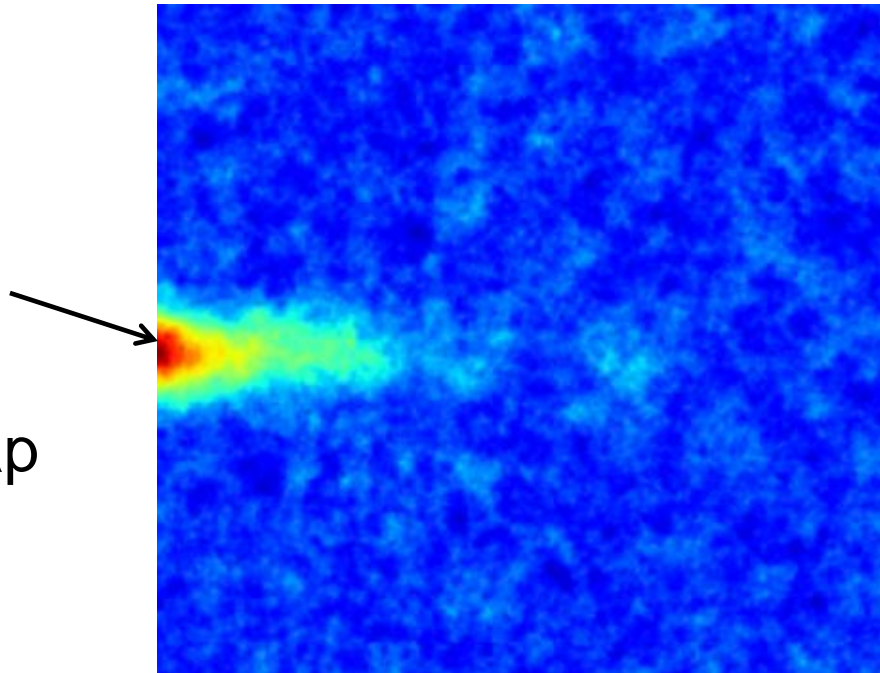
$\gamma = 4$
$\sigma = 0.05$

Local perturbation vs Natural instability

- Natural instability overwhelms seeded channel at higher roughness

Concentration fields

(a) $\sigma=0.02$ (b) $\sigma=0.05$ (c) $\sigma=0.1$ (d) $\sigma=0.2$

Seeded channel dominates natural instability

Seeded channel overwhelmed by natural instability

Conclusion

- There are consistent features in dissolution patterns across different initial conditions

- Coarsening of dissolution patterns
  - $N \propto L^{-1}$

- If the irregularities are large enough, natural instability can still overcome the seed

Acknowledgements

- U.S. Department of Energy
- National Science Center (Poland)
- Dr. Anthony J. C. Ladd (Department of Chemical Engineering, University of Florida)
- Dr. Piotr Szymczak (Institute of Theoretical Physics, Warsaw University, Poland)

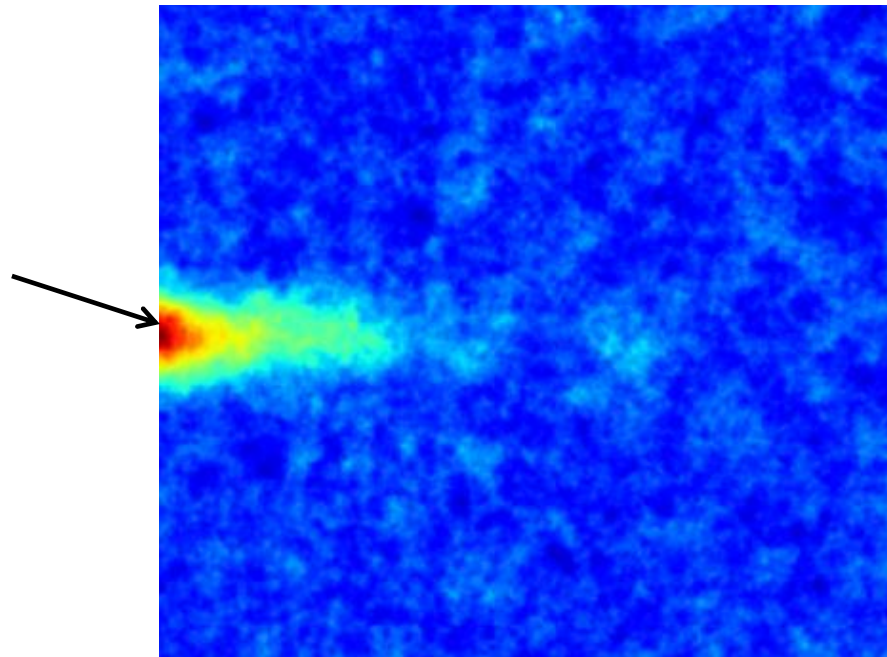# Thank you for your attention!

Questions?

Extra slides

Introducing a seeded channel

- Does introducing a seeded channel affect the dissolution pattern?
- Does the RII still overcome the seed?

$$h(x,y) = h(x,y) + 0.1e^{-0.05x}e^{-0.01(y-W/2)^2}$$

Seeded channel

$\gamma = 4$
$\sigma = 0.05$